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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

CALIFORNIA'S EXPERIENCE WITH CONCRETE PAVEMENTS

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61-11

Prese DND Conference

April 1961

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Fifty years ago, there were few, if any, paved roads in California outside of the cities. Beyond the city limits, a traveler was forced to endure the dust or mud of the earth roads as only a relatively small mileage of rural highways had been surfaced with gravel or water-bound macadam. With the organization of the State Highway Commission in 1911, the construction of paved roads began to extend beyond the limits of incorporated cities.

The standard "high type" pavement in 1912 consisted of a concrete base 4-in. thick surfaced with approximately 1¼-in. of sheet asphalt. After a year or so the design was changed eliminating the sheet asphalt and substituting a thin asphaltic surface approximately 3/8-in. in thickness which was thought to be better than the exposed concrete for horse drawn traffic. As the years passed, there was often a time lag between the construction of the concrete base and the placing of the "oiled top." During this time, automobiles were increasing and horse drawn vehicles diminishing in number. It was finally concluded that the so-called concrete bases were good enough for traffic without the asphalt surface and therefore this asphaltic top course was abandoned and the concrete base became the pavement.

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The standard design for concrete pavements was a continuously poured slab 4-in. in thickness and 15-ft. wide which often developed cracks over the heavy clay soils, Fig. 1. With increased traffic, criticism of these narrow pavements became rather marked and, in fact, it was one of the factors in the political campaign for Governor in 1924. In 1923, the standard was increased to a 5-in. depth and the width to 18-ft. However, with the election of a new Governor and the appointment of a new State Highway Engineer in 1924, the standard width of pavement was increased to 20-ft. Because of rather extensive failures in the original relatively thin concrete pavements over poor soils and where irrigation had saturated the terrain the new Engineer decided that it was necessary to construct better bases and foundations for the concrete pavements and therefore State Highway Engineer R. M. Morton embarked on a broad policy of first constructing gravel roads before attempting a more permanent type of surface. About 1929, California began to control the compaction of embankments and subgrade soils and engineers were led to believe that if soils were thoroughly and properly compacted there was no need for improved base courses beneath the concrete pavements. It was nearly 20 years later before it was realized that concrete pavements should rest upon something other than silt or clay soils.

Up to about 1923, concrete pavements were constructed without provision for expansion or contraction and occasionally these thin pavement slabs would buckle or "blow up" due to expansion in hot weather, Fig. 2. Blowups of concrete pavements were experienced in most states although the tendency was much more marked with certain types of aggregates than with others. Reports from the middlewestern states, such as Kansas, indicated that the most frequent breakup of concrete pavements occurred in sections constructed with flint aggregates and these blowups were most noticeable following a thunderstorm when the wet pavement became heated under the direct rays of the sun. Engineers of the U.S. Bureau of Public Roads recommended that provision should be made for expansion and in 1924 California began to provide expansion space by leaving a timber header in the pavement when the work was stopped at noon and at the end of the day. Later, the wooden strip was removed and the space filled with a mixture of asphalt and sawdust.

Studies by the Bureau of Public Roads led to the conclusion that pavements should have joints at more frequent intervals and it was the general feeling that cracks due to contraction were objectionable and unsightly and that this cracking should be anticipated by the construction of weakened plane or contraction joints. There has been much debate among engineers as to the proper spacing for expansion joints and a great many different ideas have been expressed and innumerable materials offered to fill the joint spaces. Such materials as rubber, cork, synthetic insulating board, et cetera, were used but few proved to be satisfactory.

After an elapse of some 15 or 20 years and a great increase in heavy traffic loads, most highway engineers in the United States were again forced to change their minds and to face the fact that expansion joints were causing more trouble than they were preventing. Now it has become the style to eliminate all expansion joints although the contraction joints have been retained. To express a personal opinion, it is by no means certain that these contraction joints offer any real benefit to the life of the pavement or to the citizen who drives a vehicle and perhaps it is time to eliminate all planned uniformly spaced joints.

The development of concrete pavements in the United States has passed through several cycles. Most of these cycles of design and construction practice originated in theoretical concepts and few of these theories rested on any sound basis of investigation. Altogether too many of the design concepts have been based on assumptions without taking the trouble to find out what really takes place in a pavement subjected to changes in temperature, changes from wet to dry, changes in the nature of the soil support, and the dynamic effects of a series of heavily loaded vehicles moving over the pavement. For example, Westergaard's "K" or coefficient of subgrade reaction has been widely used in the design of concrete pavements. However, measurements of concrete slabs at different times of the day show that individual slabs curl and warp and therefore do not rest uniformly upon the subgrade at all times, Fig. 3 and 12. The question of subgrade reaction hardly appears to be relevant as large areas of the slab are not resting on the subgrade for a considerable portion of the of the day. Furthermore, it can be shown by calculation, which has been verified by tests, that the amount of pressure transmitted to the subgrade through a modern concrete pavement is not very great. The maximum amount of pressure on the soil resulting from a truck with tandem axles carrying the AASHO recommended maximum legal load limit of 32,000-lb. is in the order of 7 psi beneath an 8-in. concrete slab. For comparison - the designers of military equipment have found that a heavy vehicle, such as a tractor or tank equipped with a caterpillar or track layer type of support, can travel anywhere over ground that will support a man on foot provided that the area in contact with the ground is large enough to reduce the pressure to approximately 8 psi. It does not appear therefore that engineers need be greatly concerned over the modest pressures transmitted to the subgrade soil through a concrete pavement. Any distress or failure that may develop must be attributed to some other cause or mechanism.

Engineers have long realized that water is the most widespread and basic cause for distress and failure in all types of pavement. There is no doubt that this is a correct conclusion. However, most engineers then assume that the adverse effects of water can be eliminated or minimized by "drainage," and in the case of pavements it is widely believed that water may be prevented from getting into the soil beneath pavements if one places a seal coat over asphaltic surfaces or carefully fills and seals the cracks and joints in concrete pavements. A vast amount of money has been spent throughout the years and a variety of materials used in attempting to provide permanent seals for the expansion and contraction joints. However, there is little evidence to show that any of these efforts have been consistently successful for more than a brief period of time. Even though it were possible to seal all cracks and joints tightly, water can enter at the edges of the pavement, and the amount of vertical movement which the slabs undergo makes it more or less hopeless to maintain a seal or to prevent water from getting under the pavement slab. Water may enter by infiltration along the edges or by condensation of vapor and when the slab ends have curled upward and are traversed by heavy vehicles there is created a very effective type of diaphragm pump. If constructed of durable concrete and not subject to damage from chemical attack or by freezing and thawing, concrete pavements rarely show serious distress except as an aftermath of pumping which removes the subgrade support, Fig. 4.

After an extensive investigation of concrete pavements in California in the years 1944 to 1946, it was concluded that some means must be adopted to prevent the supporting soil from being pumped out by the pulsating movement of the rigid slabs. In 1946, the first pavement was constructed over a cement treated subgrade. This first project was in southern California on the coastal highway between San Diego and Los Angeles. This was followed by other sections and for a number of years all concrete pavements in California have been protected from the loss of support through pumping. The subgrade soil is mixed with either portland cement or asphalt, depending upon the nature of the material. California practice in the use of treated subgrades has been reported in a paper presented at the Annual Meeting of the Highway Research Board in January 1960[1]. The use of cement treated subgrades or bituminous treated subgrades, Fig. 5-6-7, has completely eliminated the pumping effects and as a consequence faulting at the joints, Fig. 8, has been reduced to the degree that it is practically unmeasurable on many projects. On a few sections there are occasional joints faulted in excess of 1/8-in. On many pavements 5 to 15 years of age the faulting does not exceed 1/16-in.

Aside from faulting at the joints which is usually the first evidence of distress, the development of random cracking is also a criterion of performance. While California pavements are not free from transverse cracking, Fig. 9, between the planned joints, the incidence of diagonal corner breaks, Fig. 10, is unusually low. Transverse cracks and sunken slabs adjacent to the joints have been almost entirely eliminated by the use of treated subgrades, Fig. 11.

Expansion joints have been eliminated but California still retains the practice of placing contraction joints of the weakened plane type at 15-ft. intervals. Within recent years, complaints have been registered by one of the largest manufacturers of automobiles who has found that with the particular spring suspension used the cars develop trouble in the form of excessive

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(1) "Construction Practices on Cement Treated Subgrades for Concrete Pavements," by F. N. Hveem.

vibration and shaking of the car. This has been traced to harmonic or cyclic reactions caused by the relation between the automobile and the 15-ft. spacing of joints, Fig. 12. Some attempts are being made to meet this criticism by varying the length of the slabs to destroy the uniform repetition. General Motors engineers suggested a spacing of 13-, 14-, 17-, 16-ft. Whether or not this irregular spacing will be effective remains to be determined. The Division of Highways is launching an extensive investigation of effects of pavement roughness on several different types of vehicles.

Most pavements in California prior to the year 1927 were constructed without contraction joints or even without planned joints of any kind. Many of these older pavements have given a remarkable performance and some are still in service after 40 years under the heaviest truck traffic. Recent reports from experimental installations in other states, Illinois, for example[2], confirm the superior performance of pavements constructed without joints. In the opinion of the author, joints in concrete pavements should be placed as far apart as possible. While irregular cracks may develop and may be regarded by some highway engineers as "unsightly", there is a great deal of evidence to show that such unjointed pavements will give better service to the traveling public. This view, however, does not necessarily represent the opinion or present policy of the California Division of Highways. As stated before, contraction joints in California pavements are

(2) "Experiment in Pavement Slab Design," W. E. Chastain, Sr. and John E. Burke, Proceedings at the Highway Research Board, Jan. 1960.

still being placed at approximately 15-ft. intervals. Contraction joints in concrete pavements are now being installed in a diagonal pattern instead of normal to the center line. The first joints of this type were introduced as an experiment in 1927 and after some 15 years it was evident that the diagonal joints were in better condition; that is, there was less evidence of faulting in the pavement than in the adjacent normal joints. Further trial installations were started about 1950 and now diagonal joints are a standard design feature. There are definite indications that diagonal joints are effective in producing greater riding comfort and also that there is less tendency for the development of faulting. Figure 13 shows a typical plan of the pavement and joint arrangement. Figure 14 is a typical section for a concrete pavement. Except for a few experimental projects, concrete pavements in California are not reinforced and since the adoption of cement treated subgrades no load transfer devices or dowels are used at the joints. Where reinforcing steel has been used experimentally there has been no evidence of sufficient advantage to justify the additional cost.

Another method of concrete pavement construction is currently being tried out in California and elsewhere. This is the slip-form paver and two of these pavers have been used during the last three years; one, the Guntert-Zimmerman machine, was developed in California originally for paving the floor slabs in large drainage canals. This machine is equipped with electronic controls and is designed to follow a tightly stretched steel wire fastened to steel stakes about four feet from the edge of the pavement. This wire serves to establish both line and grade. The second slip-form paver is the Rex machine manufactured by the Link Belt Company. This paver is designed to follow the subgrade, and the profile of the final pavement depends largely on the accuracy with which the subgrade has been constructed. Sections of pavement have been built with either machine which are judged to have satisfactory smoothness as measured by the Profilograph, Fig. 15. However, due to a variety of causes, slip-form pavers can turn out some comparatively rough or irregular surfaces. It seems evident that in their present stage of development these slip-form pavers cannot be regarded as completely dependable and specifications must require the contractor to correct any rough pavement by grinding or cutting off the high spots. It is certainly questionable whether the possibility of reducing the cost of construction is enough to warrant employing an uncertain and undependable method for constructing such an important feature as a portland cement concrete pavement.

For the past year, California specifications for concrete pavements have carried a requirement that the surface smoothness or riding qualities will be measured by the Profilograph and wherever the pavement exceeds the specified tolerances the surface high spots must be ground down. Figure 16 shows a profilogram of several pavements; (a) is a very smooth riding surface, (b) represents the limit of tolerance now set forth in our specifications, (c) is a rough riding pavement. Figure 17 is a photograph of the type of machine used to grind down the high spots on the pavement. This machine is similar to those used for sawing joints in the concrete except that a series of cutting blades are used. Figure 18 is a close-up view of the pavement surface after the grinding. Care must be used in selecting the type of grinding operation. On one project a contractor elected to use a type of device designed for polishing concrete pavement to produce a terrazzo like finish. The resulting pavement was so smooth that a dangerous skid hazard was presented. The type of surface left by the series of narrow bladed cutting discs has a definite non-skid pattern. In fact, this device has been used to correct pavement surfaces that were found to be dangerously smooth as a result of improper finishing operations. Our new specifications will require that all concrete pavements be finished in a fashion, either with a burlap drag or other means, to produce a surface having a coefficient of friction not less than 0.25.

While the performance of concrete pavements is affected by many of the design features such as the type of subgrade support, thickness of the slab and spacing of the joints, the materials used in the concrete itself are also important. Much has been written about the principles and methods for achieving good concrete and it is not necessary to repeat these principles here. However, the foregoing evidence showing the curling and warping, expansion and contraction all indicate that volume change in concrete is very important, especially in concrete pavements. Several years ago, California adopted the policy that all portland cement used should be Type II low alkali which means that the alkali content of the cement should not exceed .6 percent. This requirement served three purposes; namely, to provide protection against sulphate attack, to prevent the alkali aggregate reaction in case reactive aggregates were encountered, and also to reduce shrinkage and expansion of the concrete. A further step to reduce the volume change was the introduction of the Sand Equivalent Test [3] to make sure that concrete sands would be free from clay; with the Cleanness Test to serve the same purpose for the coarse aggregates. Figure 19 shows the relation between Sand Equivalent test results and compressive strength. Figure 20 illustrates the variation in drying shrinkage as related to the Sand Equivalent values. Figure 21 shows the relationship between Sand Equivalent and drying shrinkage for a large number of sands from different sources.

Our next step to reduce the volume change will be a requirement designed to make sure that all portland cement will have the optimum sulphate content which requires careful control of the amount of gypsum added during manufacture of the cement. This control requires very accurate test procedures and is rendered difficult by the fact that the optimum gypsum content is usually an individual matter for each manufacturer and varies from as low as 1.4 percent to 2.5 percent depending upon the characteristics and composition of the individual cement.

(3) "Sand Equivalent Test for Control of Materials During Construction," F. N. Hveem, Proceedings of the Highway Research Board, Vol. 32, p. 238 (1953)

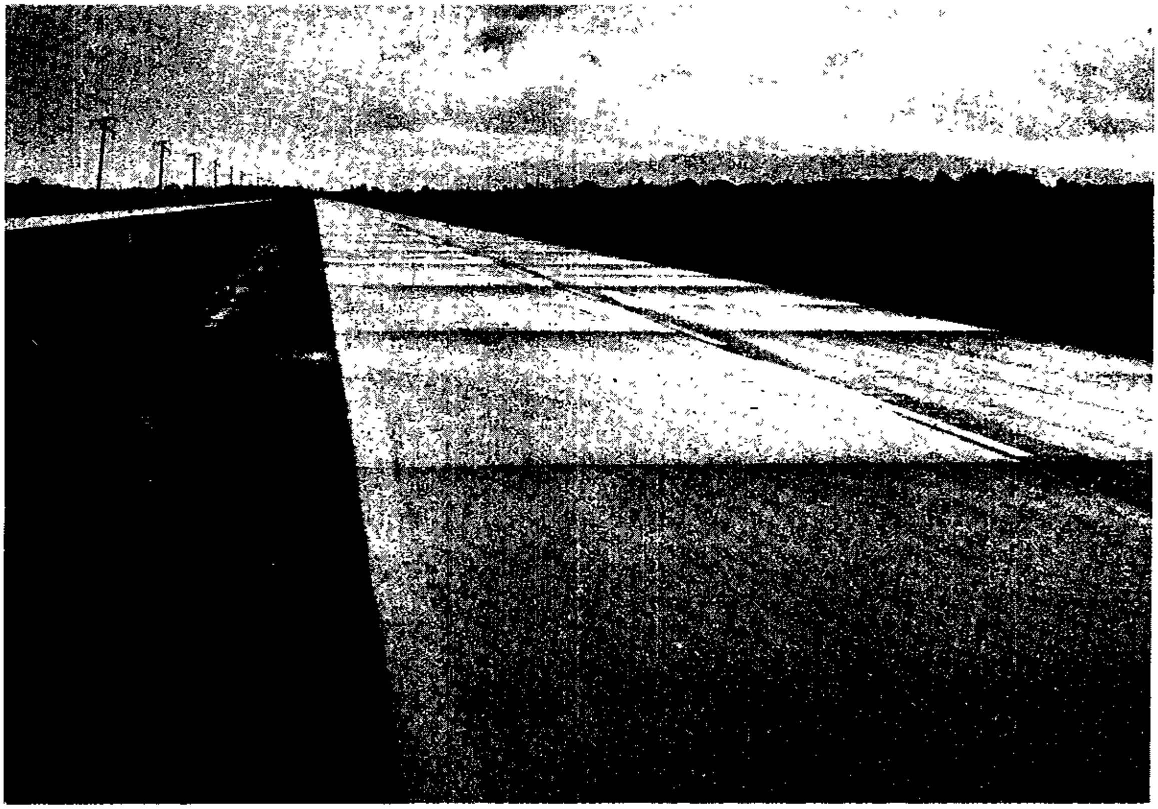
The foregoing discussion is necessarily brief and does not touch upon many important developments or aspects of pavement design. It is hoped, however, that it will convey some idea of the experience in California and the efforts being made today to secure better pavements of portland cement concrete.

Fig. 1

15-ft Concrete pavement showing wide longitudinal crack caused by expansive soils.

Fig. 2

A "blowup" due to expansion of a concrete pavement. 8" slab did not buckle.



Badly Curled Pavement

PROFILOGRAM OF PAVEMENT SHOWN ABOVE

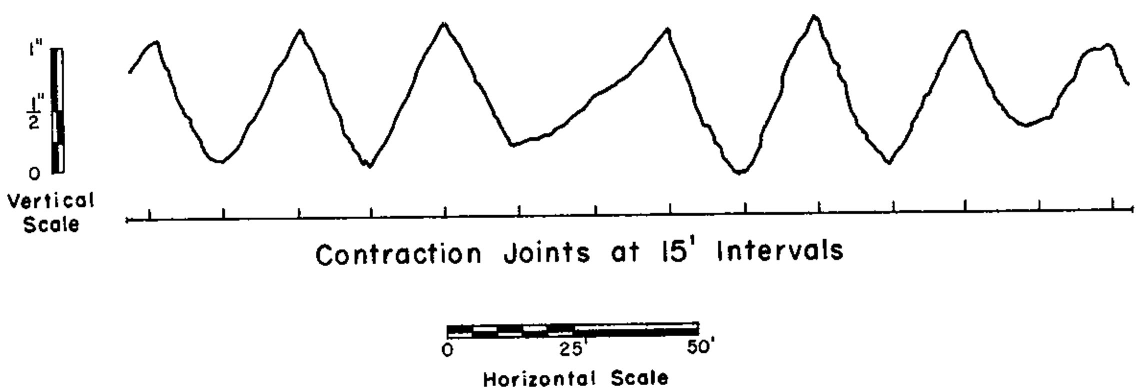


Fig. 3

Fig. 4

Showing jet of mud and water being "pumped" through a pavement joint beneath a heavy truck.

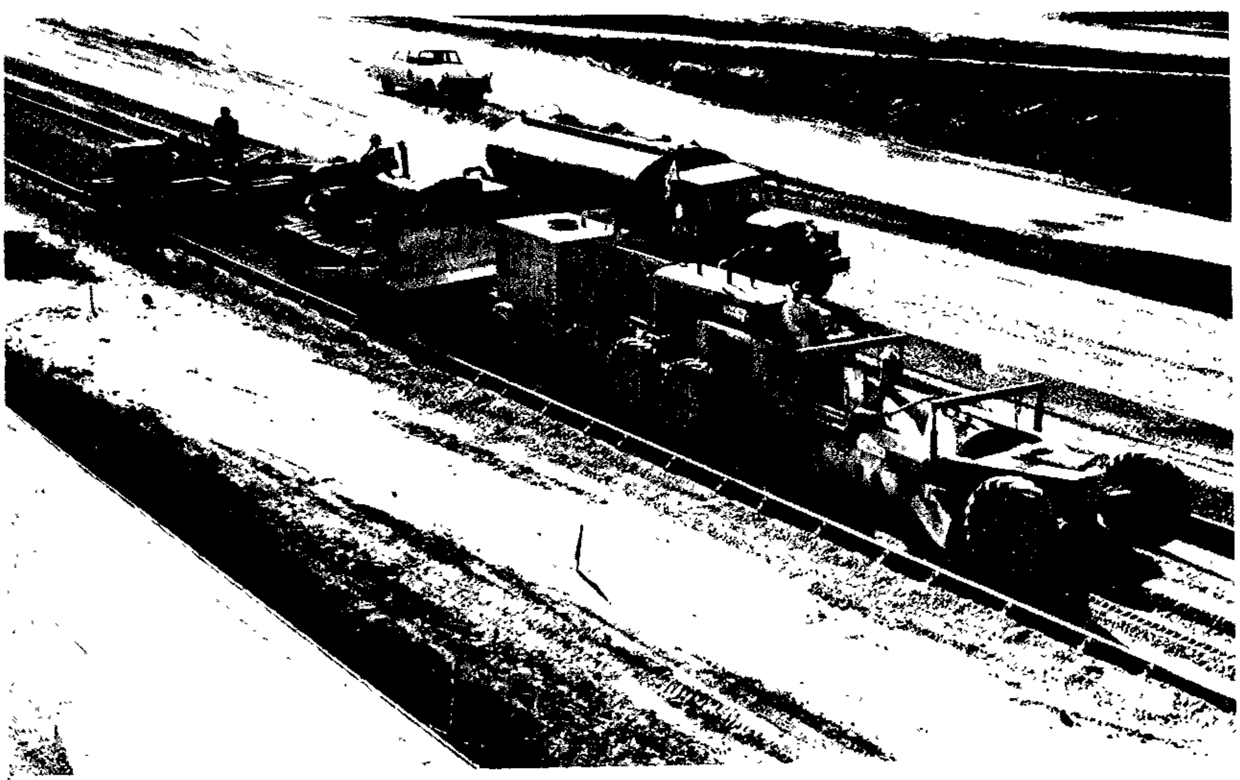


Fig. 5

Typical mixing operation for a cement treated subgrade. Road mixing equipment operating between the side forms.

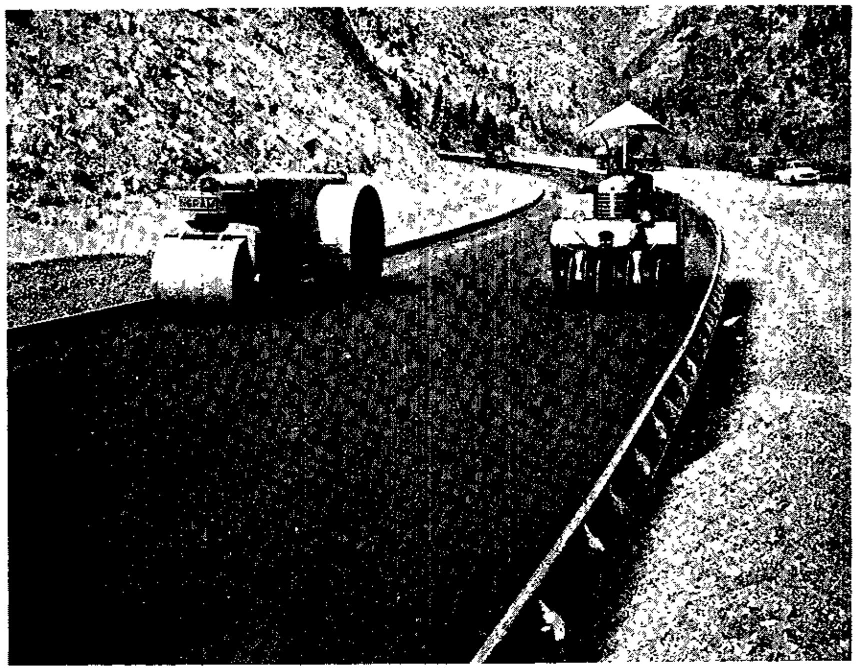


Fig. 6

Rolling the cement treated subgrade.

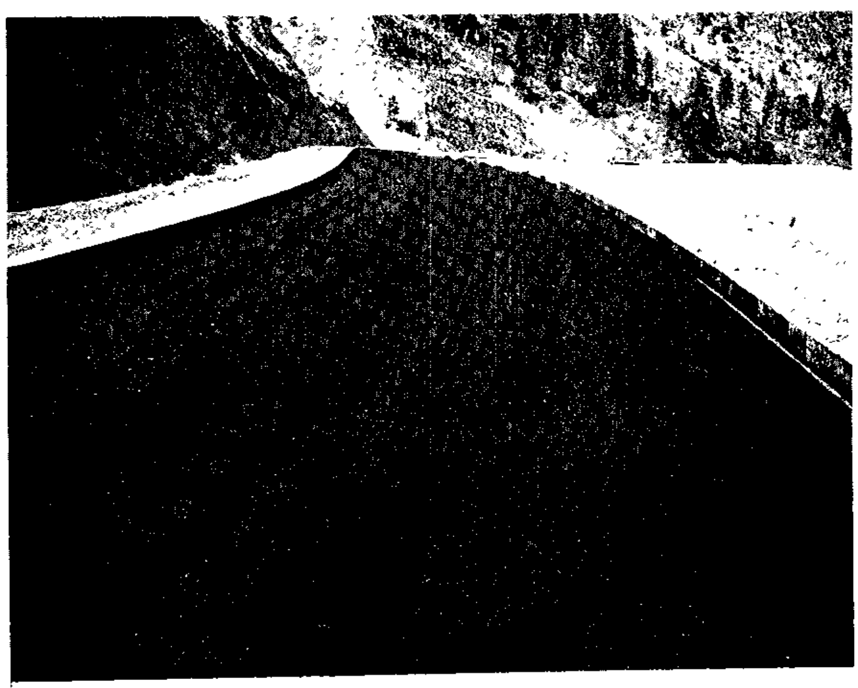


Fig. 7

Final appearance of a cement treated subgrade after a heavy application of cutback asphalt to act as a curing seal and to resist erosion.

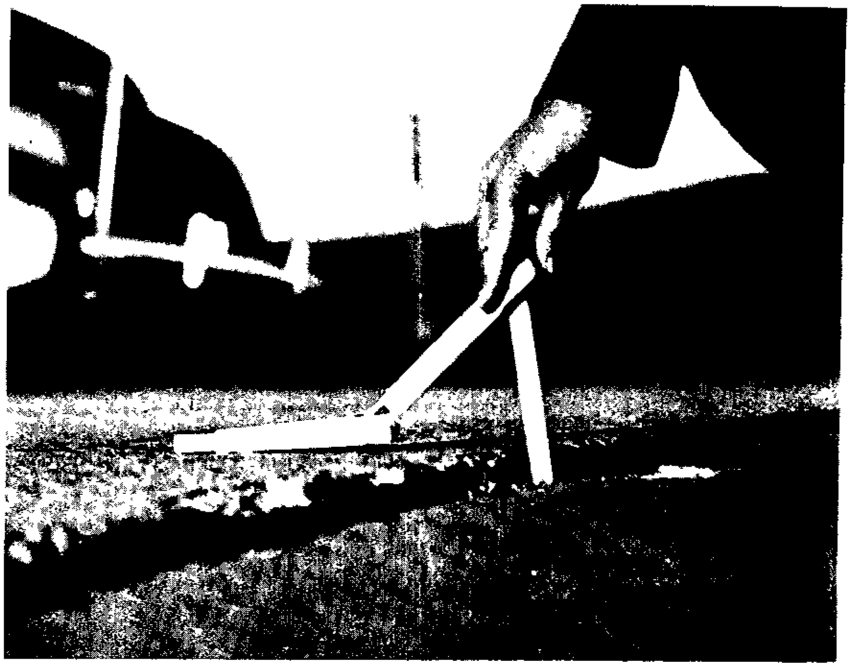


Fig. 8

Marked faulting of a transverse joint.

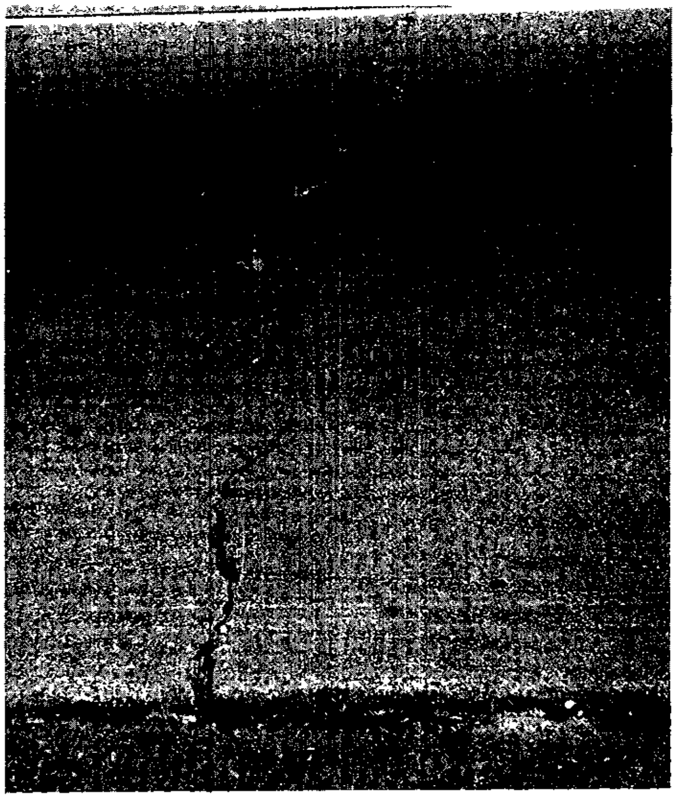


Fig. 9

Transverse cracking in concrete pavement.

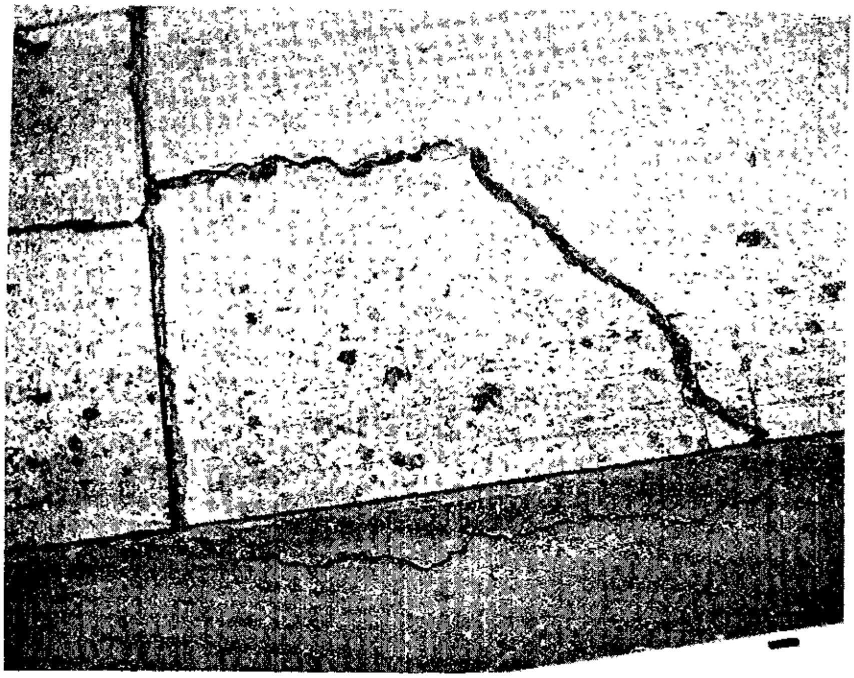


Fig. 10

Corner break in concrete pavement.

Fig. 11

Transverse breaks near a joint caused by pumping out of subgrade material and consequent loss of support.

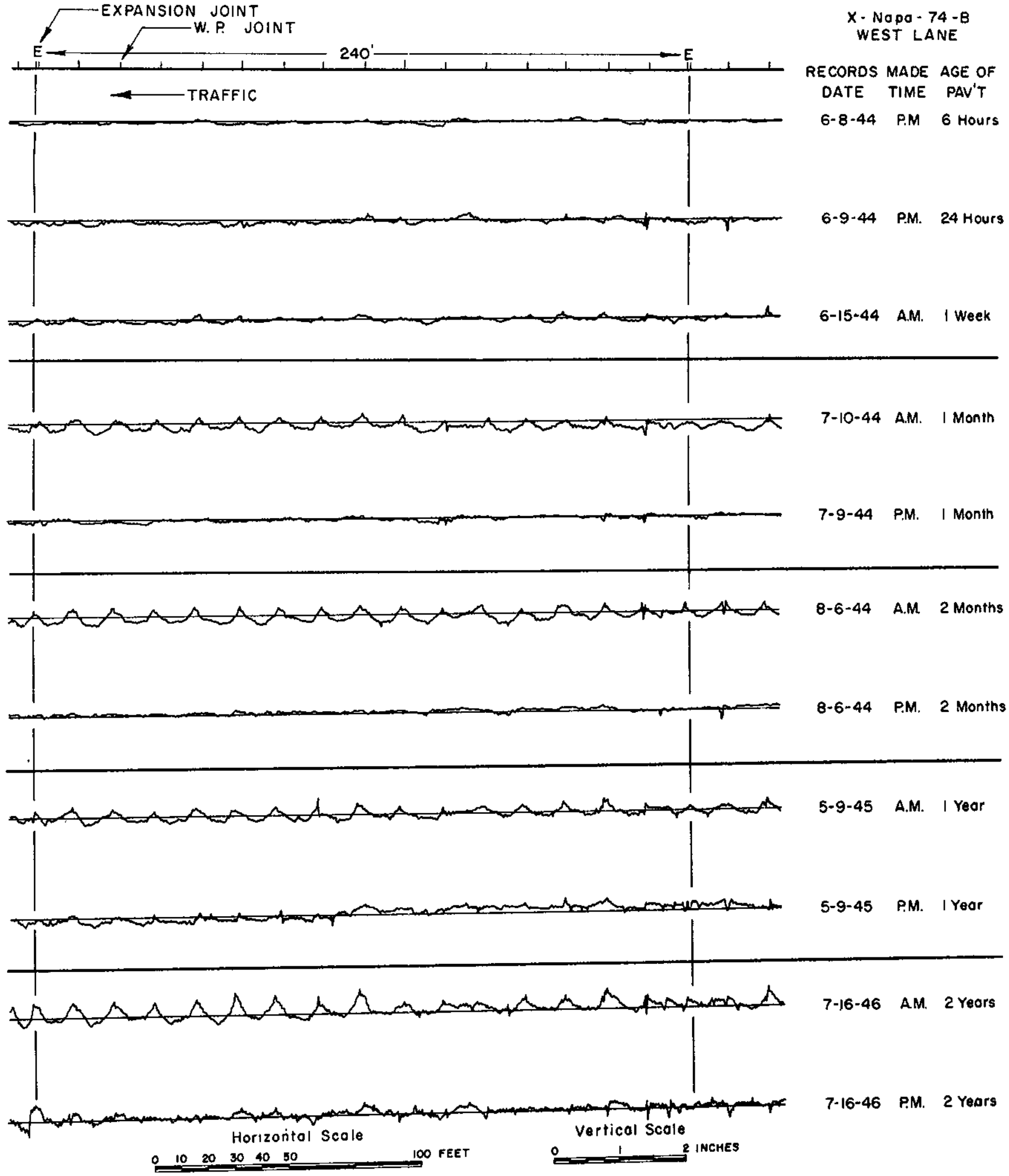
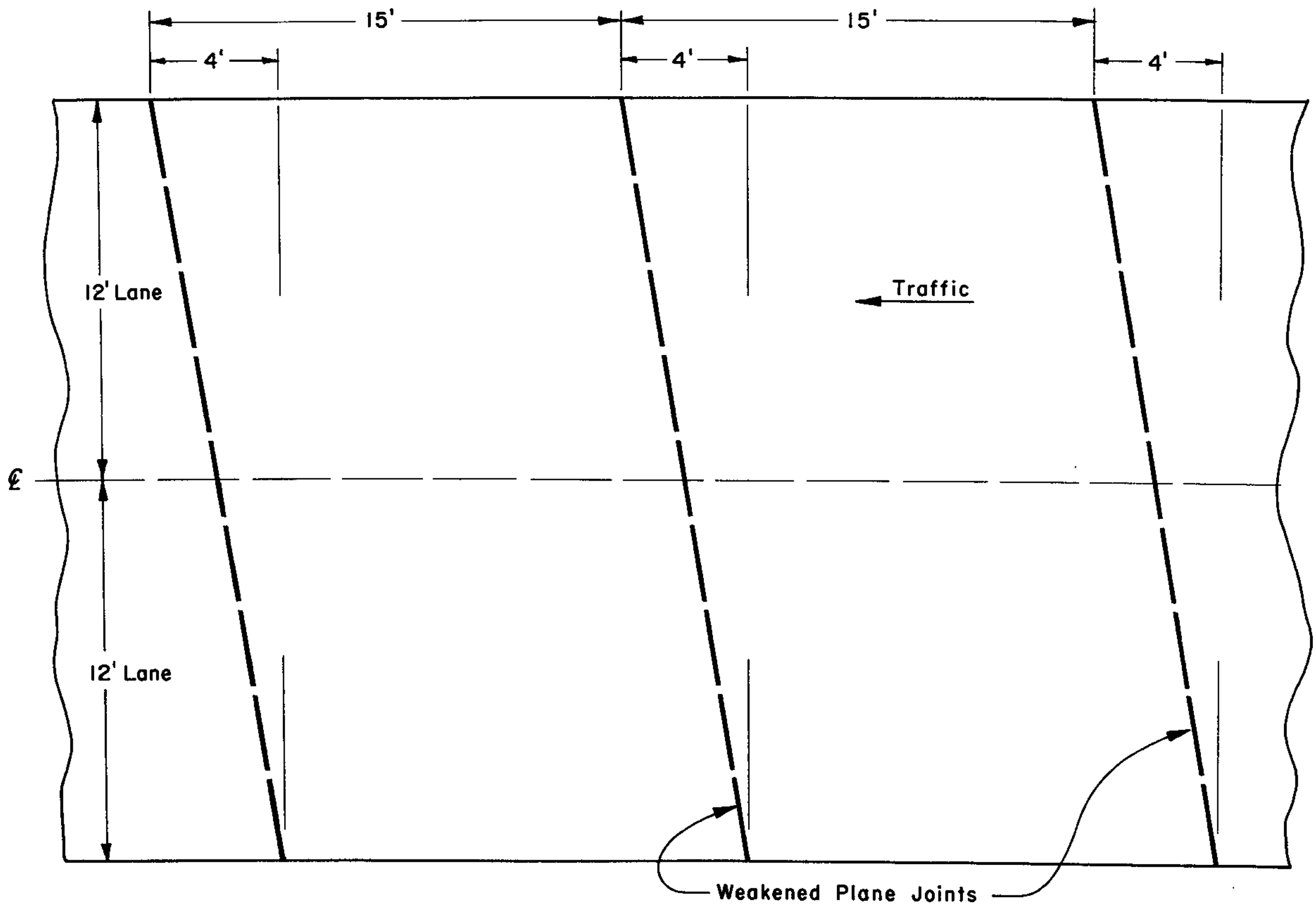


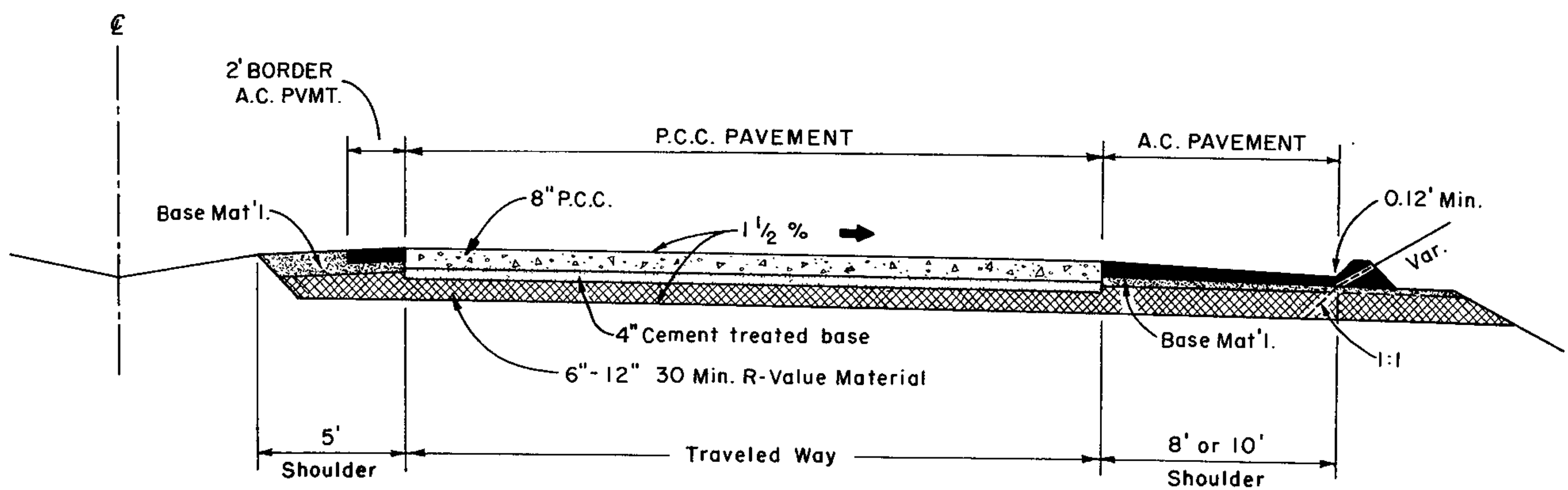
Fig. 12

Chronological record showing daily changes in the contour of a concrete pavement resulting from the curling or warping of the slabs in the early morning when the pavement surface is relatively cold.



TYPICAL LAYOUT OF THE DIAGONAL CONTRACTION JOINTS

Fig. 13



TYPICAL SECTION

Fig. 14

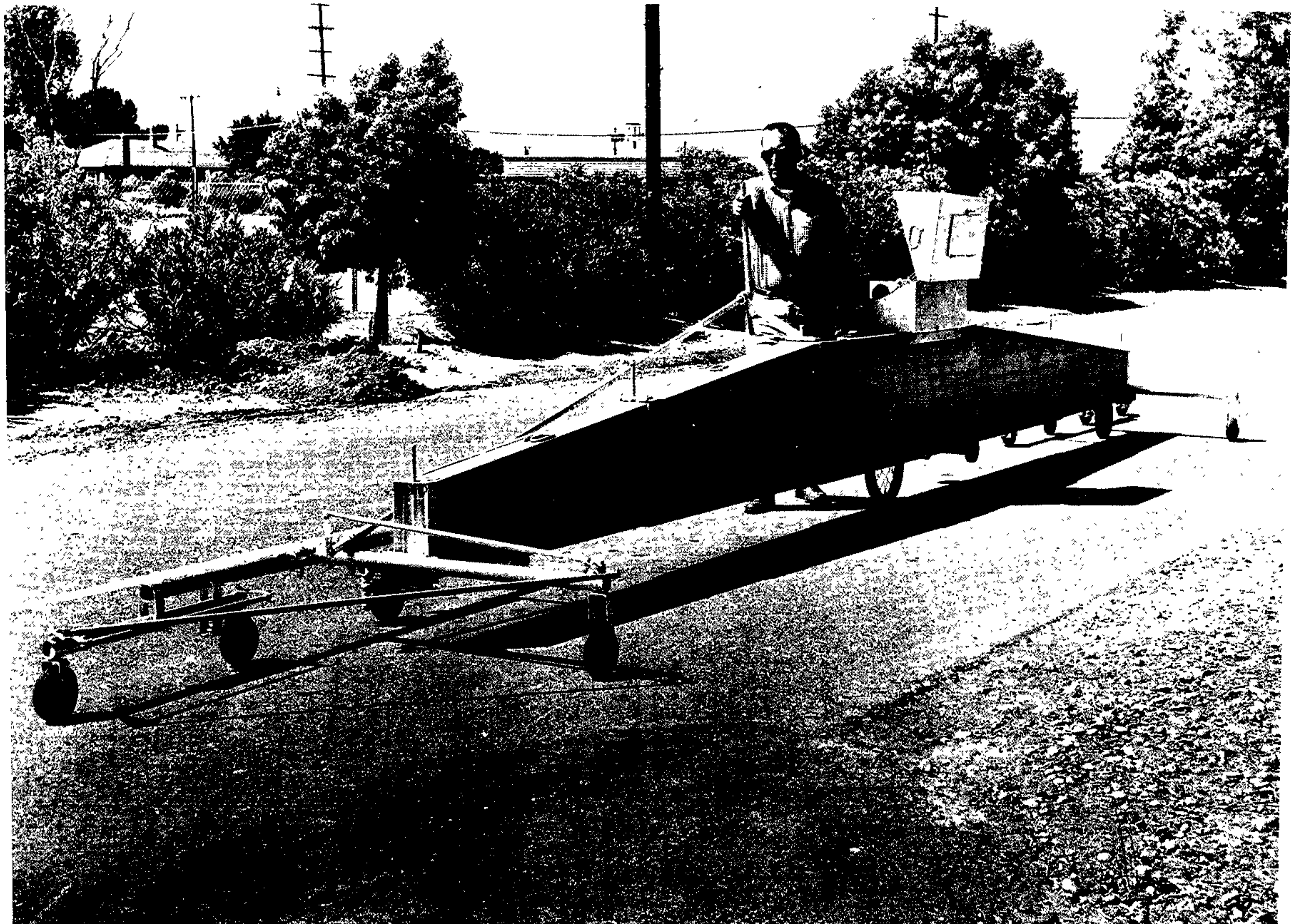


Fig. 15

Hand propelled Profilograph.

PROFILOGRAMS OF NEWLY CONSTRUCTED CONCRETE PAVEMENTS

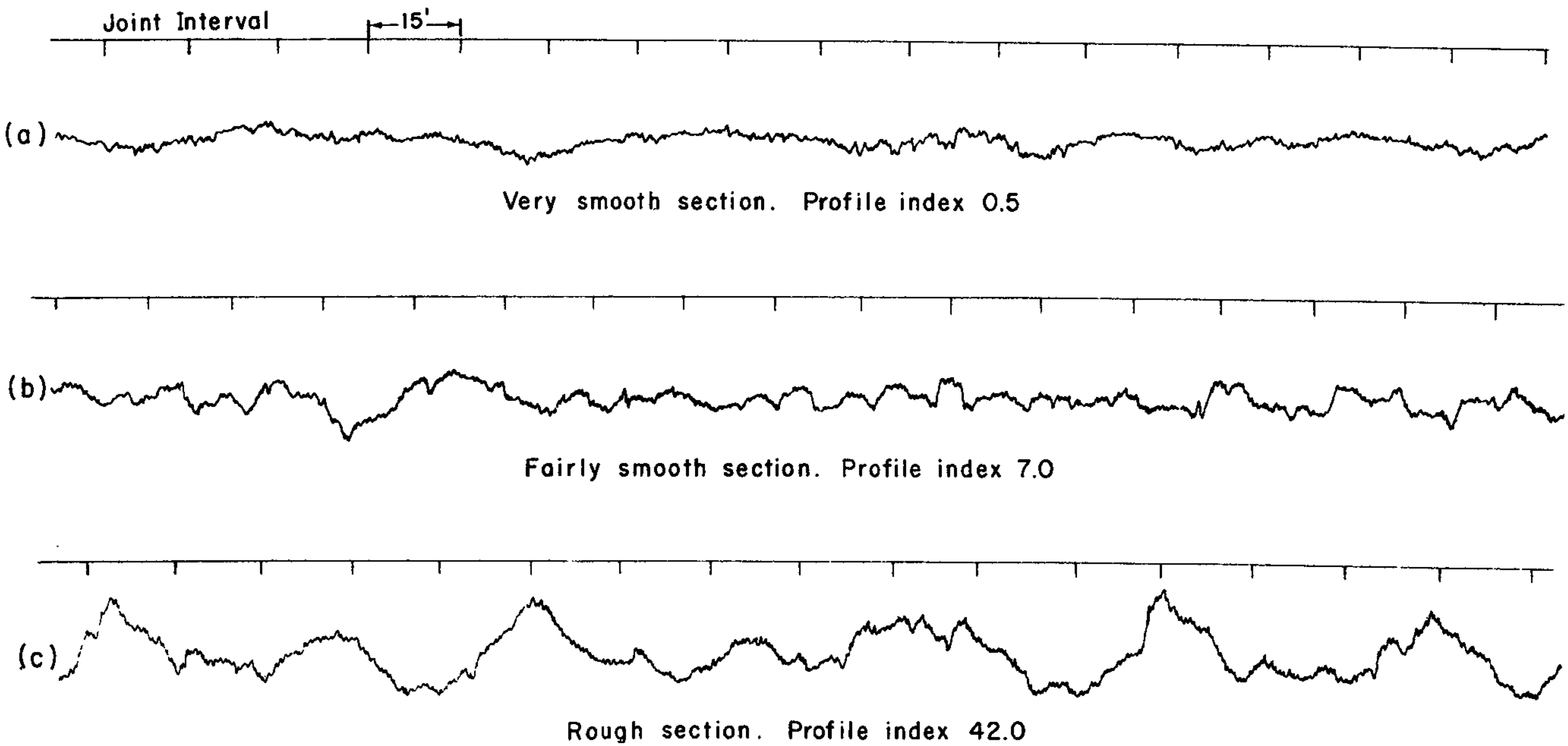
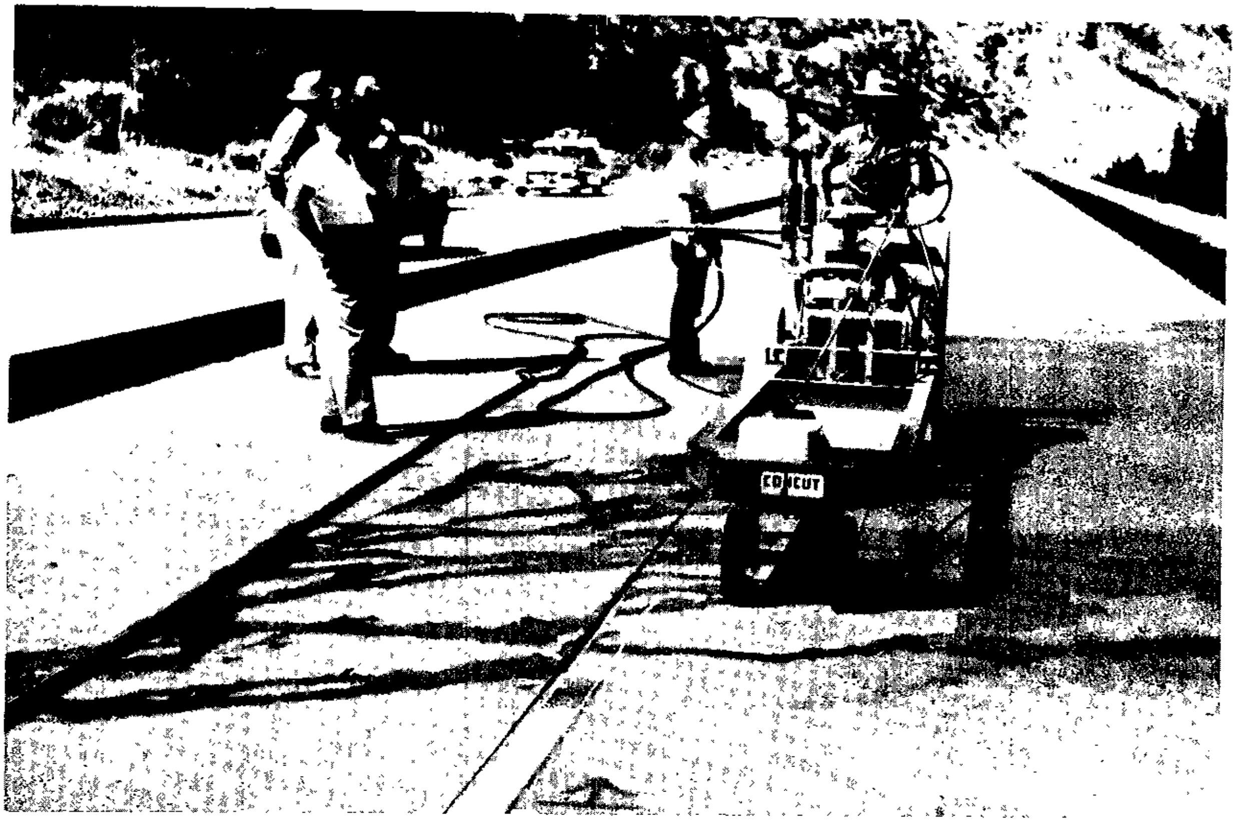


Fig. 16



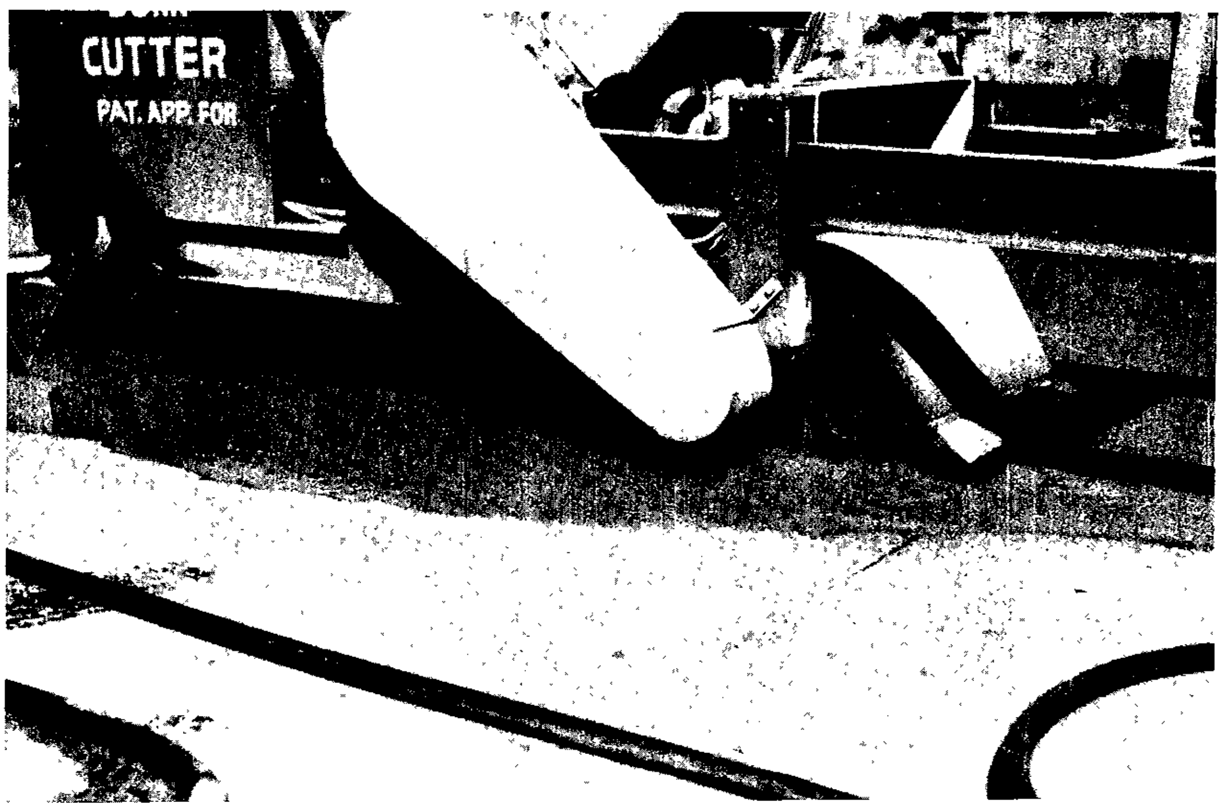
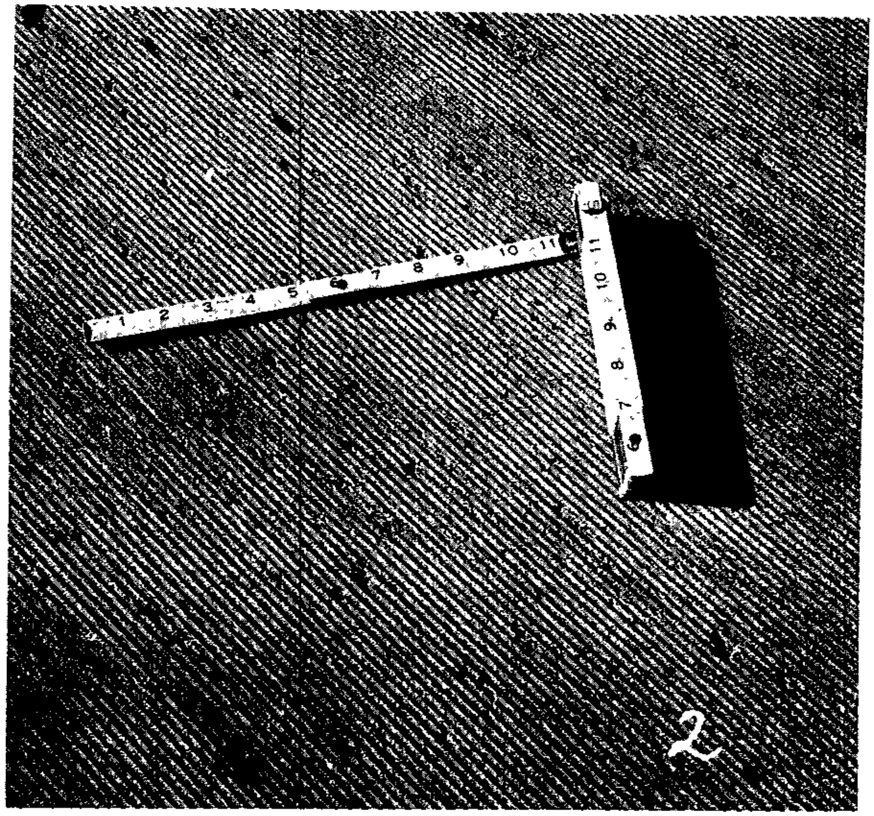
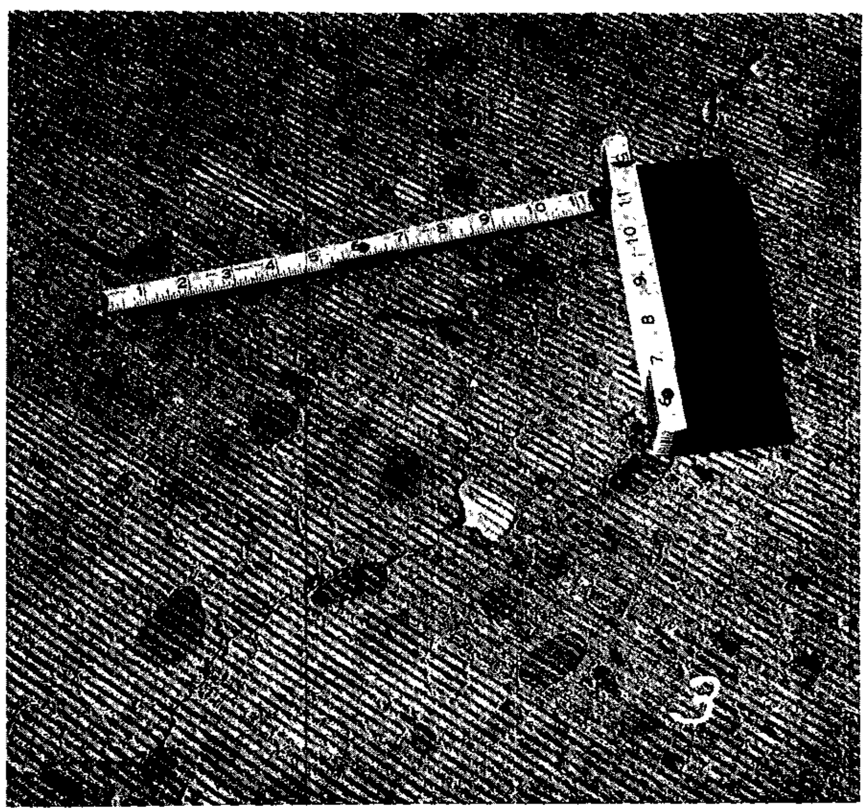


Fig. 17

Pavement grinder.



(a) Ground through mortar only.



(b) Ground through mortar and rocks.

Fig. 18

Pavement surfaces after grinding.

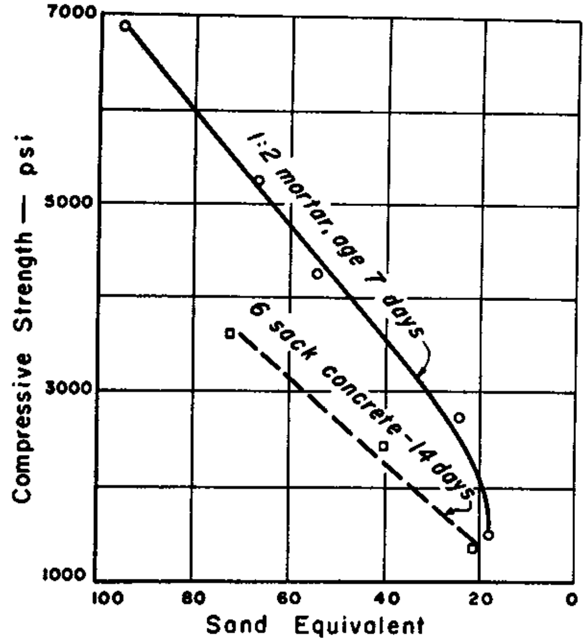


Fig. 19

Sand Equivalent versus psi.

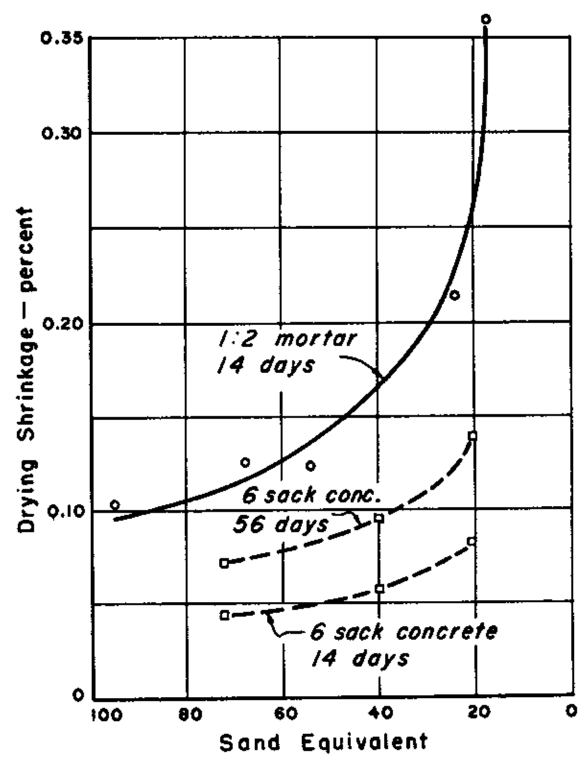


Fig. 20

Sand Equivalent versus shrinkage.

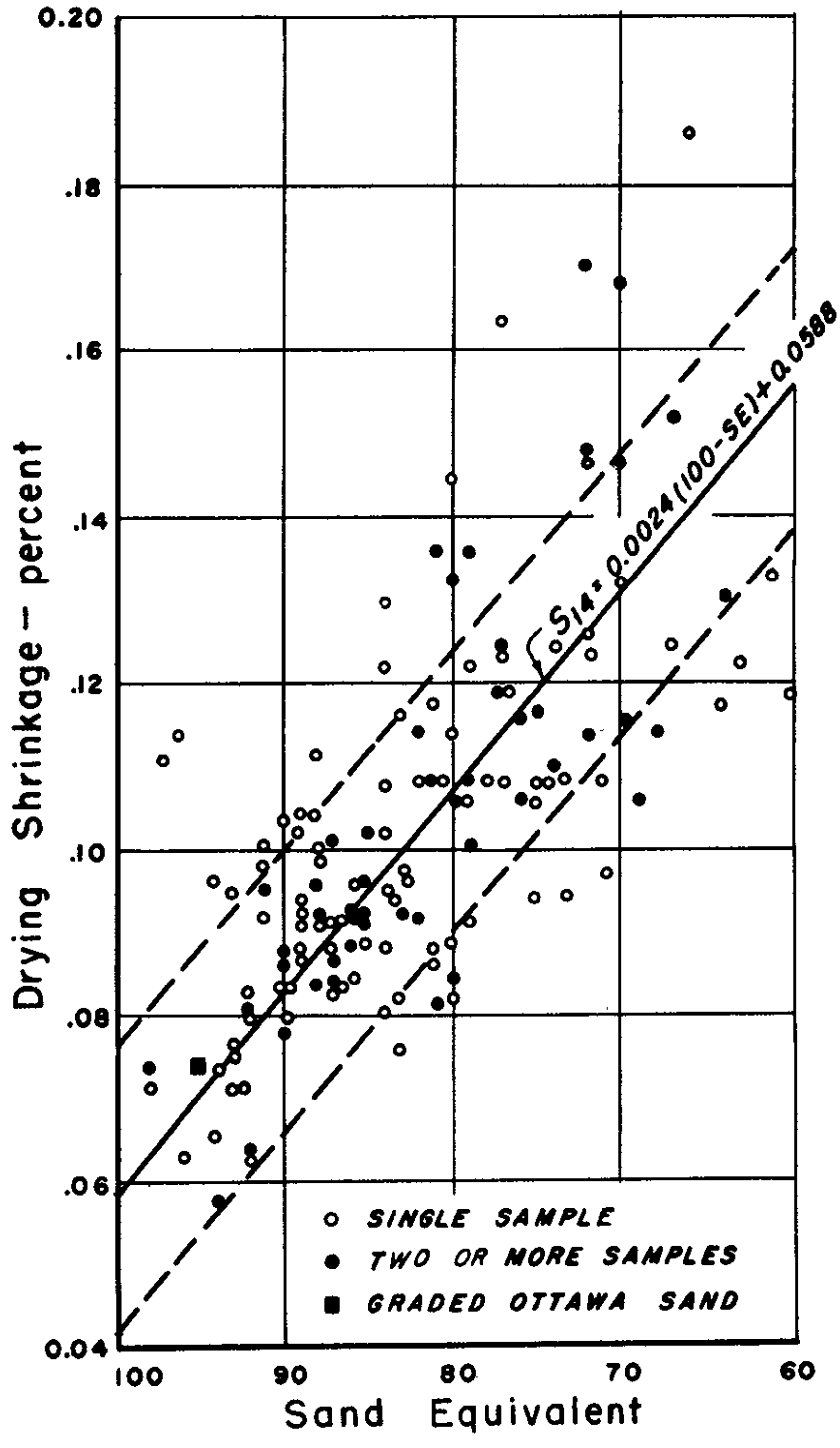


Fig. 21

Sand Equivalent versus drying shrinkage.

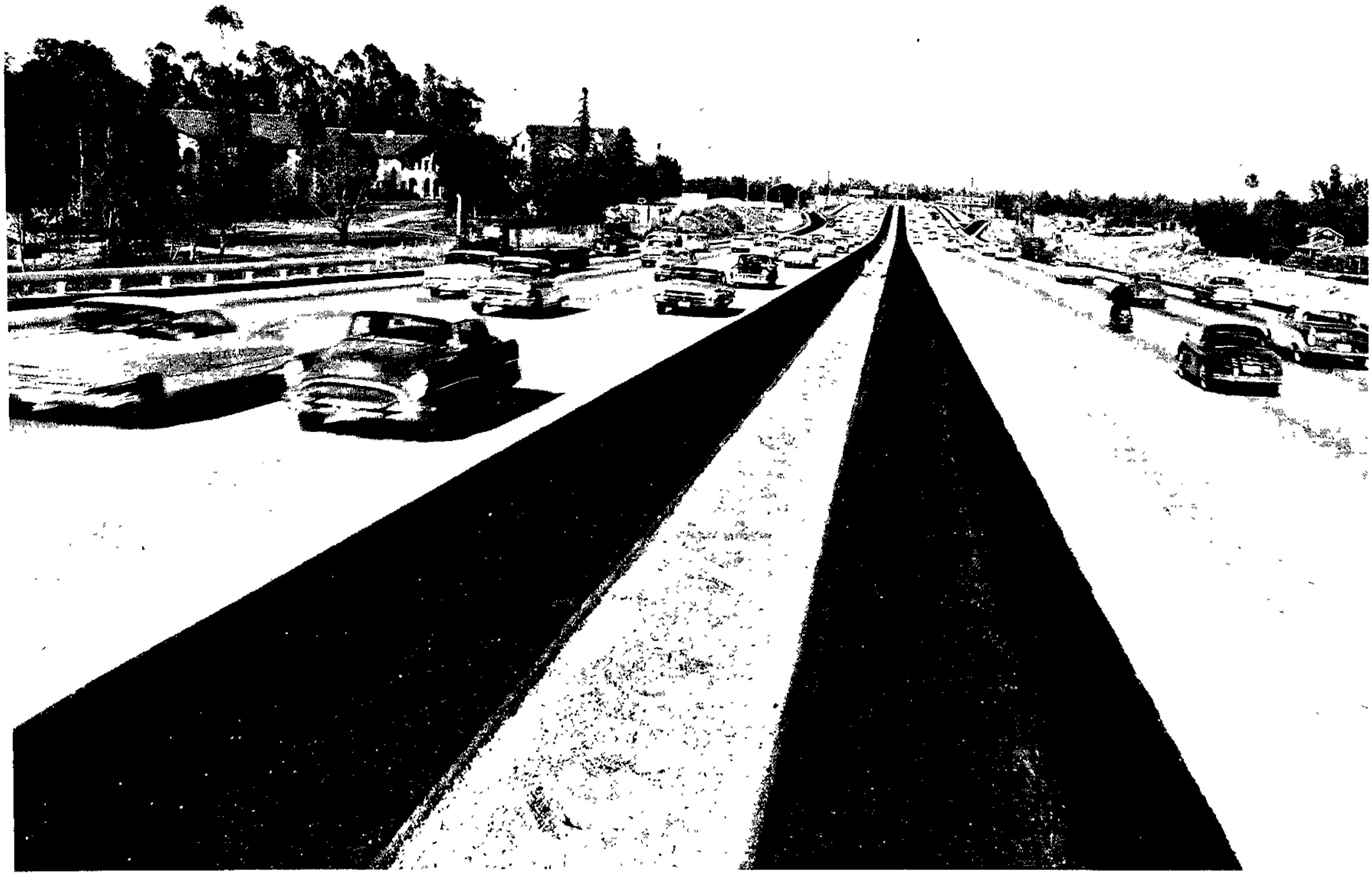


Fig. 22

An eight lane portland cement concrete freeway.